Pestic. Sci. 1996, 47, 225–233

Monitoring the Exposure of Barn Owls to Second-Generation Rodenticides in Southern Eire

Charles V. Eadsforth,* Alan Gray & Elizabeth G. Harrison

Shell Research Limited, Sittingbourne Research Centre, Sittingbourne, Kent, ME9 8AG, UK

(Received 10 May 1995; revised version received 2 January 1996; accepted 24 January 1996)

Abstract: In an extensive field study conducted over five counties in southern Eire during the winter of 1988–89, 19 Barn Owl (*Tyto alba*) roosts and/or nests were located. The local farmers and landowners within about a one-mile radius of the Barn Owl sites were surveyed concerning their use of rodenticides and observations of any secondary rodenticide toxicity effects. Regurgitated owl pellets were collected: (a) for dissection and prey analysis, and (b) for chemical analysis to determine residues of the second-generation rodenticides, brodifacoum, difenacoum and flocoumafen.

Most farmers interviewed used rodenticide baits (73%), and almost all (92%) stated that they took precautions to protect domestic and wild non-target animals. The four rodent species, brown rat, wood mouse, house mouse and bank vole provided 83% of the Barn Owl diet, and birds contributed another 12%. At least 97% of the 89 pellets analysed contained less than the limit of determination of the three second-generation rodenticides, 0·01–0·02 mg kg^{-1} of each isomer. Apparent residues in the remainder were likely to be the result of interference from co-extracted material. These results indicated that during the monitoring period, none of the owls studied was exposed to significant residues of these rodenticides in their prey.

Key words: rodenticides, Barn Owls, residues, pellets, exposure, Eire

1 INTRODUCTION

Rodents are important pests in and around farms and urban developments. Many different methods have been devised for their control, but, in practice, effective control relies largely on the use of rodenticide baits. Second-generation anti-coagulant rodenticides such as brodifacoum, difenacoum and flocoumafen are more toxic to rodents than the first-generation anti-coagulants and are active against rodents which have developed resistance to the latter compounds.[1] In recent years there has been concern about the potential for secondary poisoning of predators and scavengers from residues of anti-coagulant rodenticides in their prey. The Barn Owl (*Tyto alba* Scop.) is a night-hunting predator that feeds on live rodents and birds[2] and may therefore be at risk from the use of such baits.

The environmental risk of rodenticide use depends not only on the toxicity of the rodenticide but also on the exposure of the non-target animal. As part of a large programme of work undertaken to examine the potential environmental hazards of rodenticide use on farms the inherent toxicity of second-generation anti-coagulants to the Barn Owl has been investigated,[3,4] and a non-invasive method for monitoring the exposure of Barn Owls to such rodenticides has been developed.[5,6]

In a comparative toxicity study,[4] captive-bred Barn Owls were fed separately brodifacoum, difenacoum and flocoumafen over a period of 15 days via rodenticide-fed mice, in an attempt to simulate the potential route of exposure in the wild. For each rodenticide, the owls survived a 15-day cumulative dose of at least 1·9 mg kg^{-1}

* To whom correspondence should be addressed at: Shell Research and Technology Centre, Thornton (OPRTE/1), PO Box 1, Chester, CH1 3SH UK.

of owl body weight. This is equivalent to the consumption of two 25-g mice, with a rodenticide residue of 1 mg kg^{-1}, each day for 15 days. This was the typical concentration of flocoumafen found in rats and mice collected in farm trials with flocoumafen wax block bait using the pulse baiting method.[7] Chemical analysis of rodenticide residues in regurgitated owl pellets has been shown to be a sensitive, non-invasive method for monitoring the exposure of Barn Owls to second-generation rodenticides in their prey. The method was initially validated in a single-dose feeding study using radio-labelled flocoumafen,[5] and subsequently as part of the previously mentioned toxicity studies,[3,4,6] in which the owls were fed over a number of days. In these studies, an overall average of approximately 25% of the amount of rodenticide consumed daily was regurgitated in owl pellets during the 24 hours following each feeding.

This paper presents an extensive field study conducted over five counties in southern Eire during the winter of 1988–89 to evaluate the non-invasive monitoring method in the natural environment and to survey the rodenticide use by local farmers. Eire was considered an appropriate location for such a study, because from the early 1980s farmers had been using second-generation rodenticides for rodent control where Barn Owls might be living and hunting. The work was carried out during the winter season when rodents face a shortage of food, and rats, in particular, move from fields, ditches and hedgerows onto farms for a more reliable source of food. Farmers use rodenticide bait during this period to control these pests.

Nineteen Barn Owl roosts and/or nests were located and a survey was conducted of the farmers and landowners within a one-mile radius of the owl sites. Information was obtained on their rodent control methods, the proximity of the owl sites to farm buildings, safety precautions and any evidence of secondary toxicity effects. Regurgitated owl pellets were collected from these sites, dissected and the prey species recorded. Certain of the pellets were then analysed for residues of brodifacoum, difenacoum and flocoumafen.

Brodifacoum: 3-[3-(4′-bromobiphenyl-4-yl)-1,2,3,4-tetrahydro-1-naphthyl]-4-hydroxycoumarin
Difenacoum: 3-(3-biphenyl-4-yl-1,2,3,4-tetrahydro-1-naphthyl)-4-hydroxycoumarin
Flocoumafen: 4-hydroxy-3-[1,2,3,4-tetrahydro-3-[4-(4-trifluoromethylbenzyloxy)phenyl]-1-naphthyl]-coumarin

2 METHODS

2.1 Survey of Barn Owl sites and rodenticide use

During the winter of 1988–89, 19 Barn Owl roosts and/or nests were located in five counties in southern Eire, i.e. Co. Cork, Kerry, Kilkenny, Waterford and Wexford. The sites were chosen with the assistance of the Irish Wildlife Services and local naturalists, on the basis of recent Barn Owl activity as indicated by the presence of freshly regurgitated pellets.

Using Ordnance Survey maps, enlarged maps were drawn of the area around the Barn Owl sites. The site, farms, other buildings and geographical features within about a one-mile radius of the sites were marked on these maps. This radius was chosen because the typical hunting range for a Barn Owl is within one mile of its nest or roost.[8] The farmers or landowners within these areas were then surveyed to ascertain whether they were using rodenticide bait and if so, which type, how much, when and where. They were asked about possible hazards to non-target animals and what safety precautions were being employed. Questions were also asked about whether any non-target animals had been observed trying to eat the rodenticide bait or scavenge on rodent carcasses, what methods were in use for the disposal of rodent carcasses, and whether any dead non-target animals had been found on their farms. For consistency pre-printed questionnaires were used for this purpose.

2.2 Pellet collection

During the first visit to each site, all the existing pellets were removed so that any subsequent pellets collected would be of a known age. Some of the pellets were subsequently discarded because they were obviously very old and broken up. Some were labelled 'old' for future dissection, identification and enumeration of prey items. Others were obviously 'fresh' having a coating of mucous, and were reserved for subsequent prey identification and possible residue analysis.

The 'fresh' pellets were collected between 24 January and 5 February 1989. These pellets were all known to be no more than two to eight days old at the time of collection. The fresh pellets were placed into individual plastic bags which were clearly labelled, sealed and stored in a portable deep freeze, which was maintained at a temperature *c.* −20°C during transfer to the laboratory. On receipt they were stored at *c.* −20°C until thawing to ambient temperature shortly prior to dissection. Following dissection they were again stored at *c.* −20°C prior to residue analysis.

It is not known how quickly Barn Owl pellets disintegrate. Certain researchers have found that they are slow to disintegrate,[9] whilst others observed that they are well weathered, friable and partly fragmented within one month.[10] Presumably, however, disintegration will occur at different rates depending on the extent of exposure and the season. For the purposes of this study no attempt was made to determine the age of the old pellets. The old pellets were initially stored in paper

bags in the portable freezer. On return to the laboratory, the pellets were allowed to dry out at ambient temperature (*c.* −20°C). Subsequently these pellets were transferred to Manchester University (MU) at ambient temperature for dissection, prey identification and counting.

2.3 Prey identification and quantification

The fresh pellets were analysed for prey content at Sittingbourne Research Centre (SRC) and the old at Manchester University, Department of Environmental Biology. The pellets were examined individually: they were broken up, dissected and the bones within removed and sorted. The prey remains were identified with the aid of a dissection microscope.

Mammalian prey was identified and counted using the presence of skulls and/or left and right dentaries, the highest count of these being taken as the minimum number of individuals. Published guides[11,12] were used to check small mammal identification. Often bird prey had been decapitated, so the identification and enumeration of these prey was made from post-cranial material. Due to limited reference material at SRC, it was not possible to identify the individual avian species present in fresh pellets, and thus they were separated into two groups, those of approximately House Sparrow size and larger birds of approximately Starling size. The old pellets were analysed at MU where a large reference collection enabled specific identification of all the avian species present, except in two cases where there were insufficient remains. The latter could only be identified as Starling size. Frog bones were readily identified[11] and the numbers present estimated from the number of right or left humeri or pelvic girdles.

Published values[10] were used for the average weights of the small mammals, birds and frogs present in the pellets. In addition, one pellet contained rabbit (*Oryctolagus cuniculus* L.) remains, skull fragments from a young specimen, which was assumed to weigh 350 g. Birds classified as Starling size could have been Starling (*Sturnus vulgaris* L., 82 g), Redwing (*Turdus musicus* L., 65 g) or Song Thrush (*Turdus philomelos* Brehm. 76 g), and the mean of these weights, 74 g, was used for calculations of prey weight. Similarly House Sparrow birds could have been House Sparrow (*Passer domesticus* L., 27 g), Chaffinch (*Fringilla coelebs* L., 20 g), Robin (*Erithacus rubecula* L., 19 g) or Hedge Sparrow (Dunnock, *Prunella modularis* (L.), 21 g) since all were found in the old pellets. The mean weight used for these species was 22 g.

The percentage biomass represented by each of the prey species in the diet of the Barn Owls studied was calculated. The minimum number of prey items of each species identified in the pellets was multiplied by the estimated weight of that prey, and the resultant estimated weight of each species was expressed as a percentage of the total weight of all the prey items present.

2.4 Rodenticide residue analysis

A total of 136 fresh Barn Owl pellets was collected and, of these, 89 pellets were selected for the analysis of residues of the coumarin-based rodenticides, brodifacoum, difenacoum and flocoumafen. The selection was made on the following basis: pellets from areas of high rodenticide use, all pellets containing remains on the brown rat (*Rattus norvegicus* Berk.), a random selection of those containing remains of the house mouse (*Mus musculus* L.), and a random selection of those containing prey remains other than those of the above.

The pellets were extracted by homogenisation in acetone + chloroform (1 + 1 by volume) and anhydrous sodium sulfate. Mixtures were filtered and evaporated to incipient dryness in a stream of dry nitrogen. The resulting residues were re-dissolved in methyl *tert*-butyl ether and cleaned up using pre-washed NH_2 solid phase extraction cartridges, eluting with methyl *tert*-butyl ether + acetic acid (9 + 1 by volume). The extracts were concentrated by rotary evaporation to incipient dryness, and reconstituted in the high performance liquid chromatography (HPLC) mobile phase minus the acetic acid. The rodenticide concentrations in the sample extracts were quantified by HPLC by comparison with reference standards of the three rodenticides (the purity of each >95%), each isomer being determined separately.

A Pye Unicam PU 4010 pump and Perkin Elmer ISS 100 auto sampler fitted with a 100-μl loop injector were employed in conjunction with a Perkin Elmer LS1 fluorescence detector with excitation wavelength 310 nm and emission wavelength 390 nm. Two S5 ODS-2 (5 μm) columns (Hichrom, Reading, 25 cm × 4·6 mm ID.) connected in series were eluted with acetonitrile + water + acetic acid, (80 + 20 + 0·1 by volume) at a flow rate of 2·0 ml min^{-1}. Post-column methanol + triethylamine (80 + 20 by volume, 0·2 ml min^{-1}) was added via a mixing 'T' to increase the pH of the effluent to >8 and so improve fluorescence sensitivity. Typical retention times obtained under these conditions were brodifacoum : *cis* 17·0 min, *trans* 18·7 min; difenacoum : *cis* 10·6 min, *trans* 11·8 min; flocoumafen : *cis* 12·4 min, *trans* 14·6 min.

The method was validated with each set of analyses, by analysis of control pellets obtained from captive-bred owls and control pellets fortified separately with the three rodenticides. The control pellets all contained less than the limit of determination, which ranged from 0·01 to 0·03 mg kg^{-1} depending on the weight of the pellet analysed. The majority of the recoveries were in the range 71–108%, mean 83%, and therefore the results associated with these were not corrected for the

recovery values. However, one batch of samples produced low but consistent recovery values, in the range 48 to 56%, mean 53%. This was thought to be due to the long time between sample clean-up and analysis, brought about by instrument malfunction, and so these results were corrected for the recovery values.

3 RESULTS

3.1 Barn Owl sites

The 19 Barn Owl sites, roosts and nests were nearly all found in the ruins of houses or castles. A list of the sites with the location, type of site, whether roost or nest, numbers of farmers and landowners interviewed, the proportion using rodenticides, and the numbers reporting Barn Owls on or near their property is presented in Table 1.

A map was drawn for each site and features of the local vicinity such as rivers, roads and railway lines marked. The various premises visited were indicated with a triangle. An example of a typical site in Co. Kilkenny is presented in Fig. 1.

3.2 Survey of rodenticide use

During the interviews, the person responsible for rodenticide baiting was not always available for questioning, but on these occasions as much information as possible was obtained. In almost all cases it was possible to establish whether a rodenticide was in use and to identify the product.

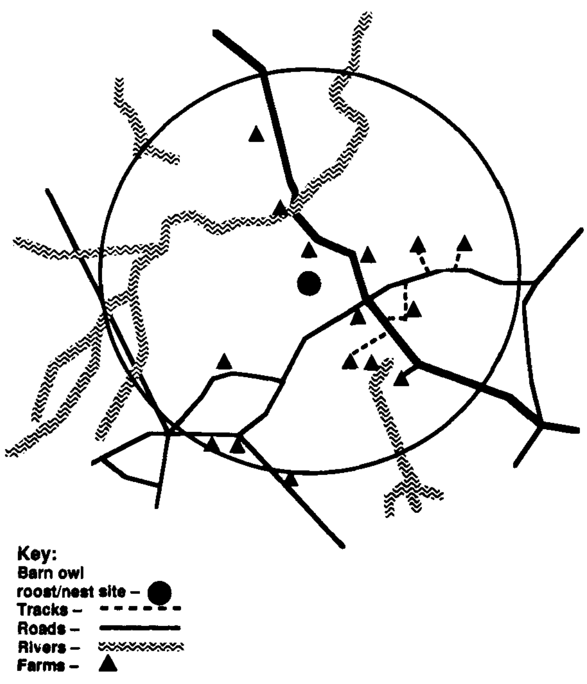

Fig. 1. Site 8, Caherleske House, Co. Kilkenny.

At the time of the survey, an average of 73% of farmers interviewed were using a rodenticide bait for rat and/or mouse control. The remaining 27% were either using cats and/or dogs, or did not require rodent control on their farms. Of the farmers using baits, difenacoum and flocoumafen were each used by 30%, bromadialone was used by 12%, warfarin by 7%, brodifacoum by 4%, chlorphacinone by 1%. The average amount of these rodenticide baits in use on these farms was approximately 8 kg per farm. The remaining 16% either used other baits or could not provide information.

The farmers were using baits both inside and outside farm buildings. The majority (92%) hid their bait in protected bait points to prevent the exposure of domestic and other non-target animals, and to protect the bait from rain.

When questioned about non-target animals scavenging dead rodents and whether non-target carcasses were ever found, interviewees answered from their total experience of rodenticide use, and not just current use. Some reported seeing animals, nine cats, four dogs and two magpies (*Pica pica* L.), scavenging on dead or dying rodents.

Of the 178 farmers interviewed about their 'life-time' experiences of rodenticide use, 11 reported incidents of dead animals which they attributed to rodenticide use, i.e. eight dogs, three cats, some crows (*Corvus corone* L.), one stoat (*Mustela erminea* L.) and one Barn Owl. However, none of these had been confirmed as poisoning incidents. One farmer had a young puppy successfully treated for rodenticide poisoning. In most cases involving dogs, the farmers took responsibility for the poisoning, having allowed their dogs access to the bait.

Barn Owls were reported in the area of their farms by 48% of the farmers interviewed.

3.3 Barn Owl carcass removal and recovery

During the period of the study, no Barn Owl carcasses were found. One farmer interviewed had found a Barn Owl carcass previously, but the flesh had been eaten by maggots and the carcass died out. It was not possible, therefore, to conduct a post mortem or residue analysis on this carcass.

3.4 Pellet collection

Between one and 20 fresh pellets were collected at each of the 19 Barn Owl roosts and/or nests during the monitoring period, with the exception of one site where none was found (Table 1). A total of 136 fresh pellets

TABLE 1
Summary of Barn Owl Roost/Nest Sites

Site No.	*Site name*	*County*	*Site type*	*Roost/nest*	*No. farmers Interviewed*	*Farmers using rodenticide (%)*	*No. farmers that saw owls*	*No. of fresh pellets collected*
1	Baldwinstown Castle	Wexford	Ruined castle	Nest	13	77	4	9
2	Grantstown House	Waterford	Ruined house	Roost	4	75	2	9
3	Butlerstown Castle	Waterford	Ruined castle	Roost/nest	7	86	2	7
4	Gracedieu	Waterford	Old house	Nest	3	67	1	6
5	Woodlands House	Waterford	Ruined house	Roost	5	100	2	2
6	Tinnypark House	Kilkenny	Ruined house	Nest	9	78	4	8
7	Newtown House	Kilkenny	Ruined house	Nest	13	77	8	6
8	Caherleske House	Kilkenny	Ruined house	Nest	9	78	4	0
9	Woodstock House	Kilkenny	Ruined house	Nest	7	43	5	8
10	St. Ann's Hill Hydro	Cork	Old hospital	Nest	13	62	1	5
11	Kilcrea House	Cork	Ruined house	Roost/nest	10	70	1	11
12	Cor Castle	Cork	Ruined castle	Nest	15	93	9	13
13	Castlecor House	Cork	Ruined house	Nest	15	73	5	20
14	Kanturk Castle	Cork	Ruined castle	Nest	6	50	0	10
15	Ightemurragh Castle	Cork	Ruined castle	Nest	14	57	6	4
16	Old Mill	Kerry	Ruined mill	Roost/nest}	9	100	3	2
17	Flesk Castle	Kerry	Ruined castle	Nest}				6
18	Ballyseedy	Kerry	Old house	Nest	14	64	6	9
19	Seaview House	Kerry	Ruined house	Nest	12	67	4	1

was collected over a period of 13 days from the sites monitored.

3.5 Prey analysis

A typical Barn Owl pellet and the range of skeletal material found in one such pellet is shown in Fig. 2.

The results of the dissections for prey analysis for all 378 pellets (old and fresh) collected from all of the 19 sites are summarised in Table 2, together with the percentage biomass represented by each prey species in the diet. The brown rat (*R. norvegicus*) was the single most important prey (by weight) comprising 35% of the owls' diet, followed closely by the wood mouse (*Apodemus sylvaticus* (L.)), 23%. Birds, 12%, house mice (*M. musculus*), 10% and bank voles (*Clethrionomys glareolus* (Schreb.)), 15%, were also frequently present. Frogs (*Rana temporaria* L.), the pygmy shrew (*Sorex minutus* L.), and the rabbit (*O. cuniculus*) made up a small part of the diet. Although pygmy shrews occurred in the Barn Owl diet in large numbers, 95 in total, they did not contribute significantly to the biomass because of their small weight (average 4 g).

Bank voles were absent in pellets collected from sites in the eastern counties of Waterford, Wexford and Kilkenny. They were, however, present in all pellets collected from Co. Kerry sites in the south-west, and those from four out of six sites in Co. Cork. In areas where the bank vole did not feature, the Barn Owl diet (by weight) was predominantly the brown rat and wood mouse, 42% and 26% by weight, respectively. House mice and birds, 13% and 12%, respectively made up the majority of the remainder. Where the bank vole was present it was the single most important prey, 34%, with the brown rat and wood mouse contributing 26% and 19%, respectively. Again house mouse and birds, 5% and 12%, respectively made up the majority of the

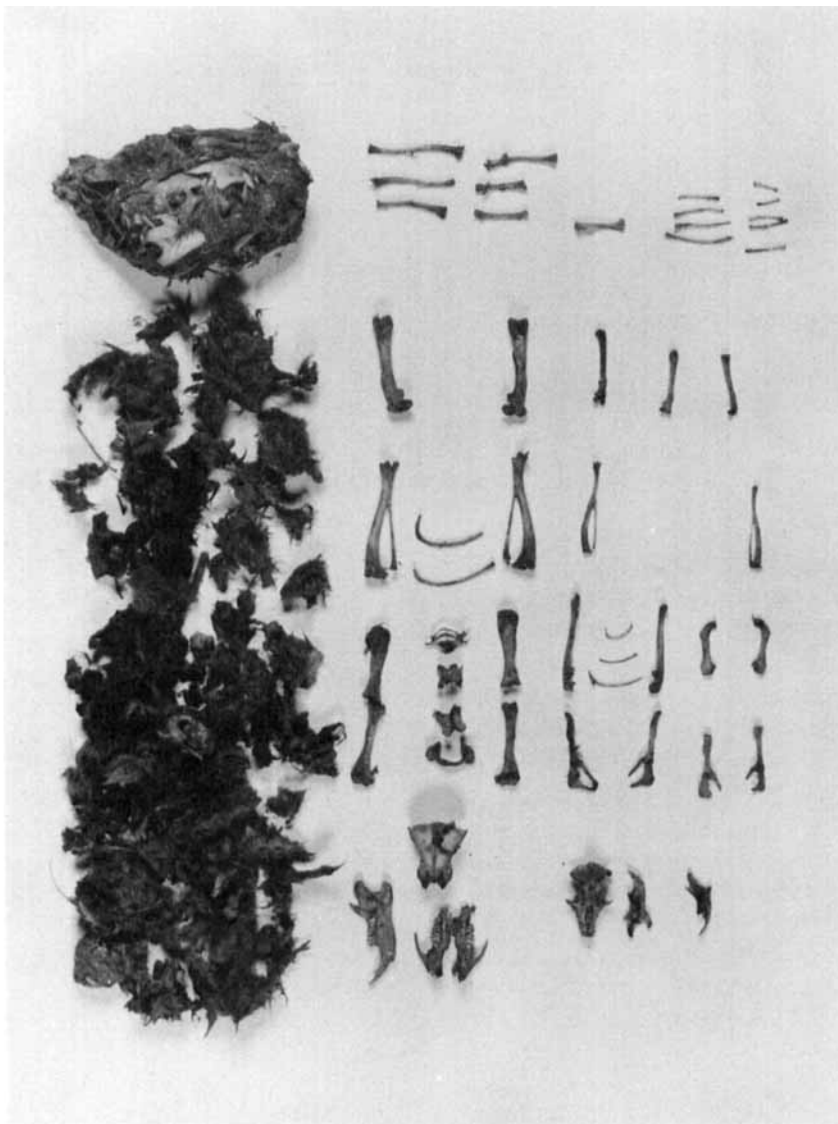

Fig. 2. An example of a dissected pellet, with some of the skeletal material removed from the fur and skin matrix.

TABLE 2
Minimum Number of all Prey Species found in 378 Barn Owl Pellets indicating their Relative Importance in the Diet

Species	Min. No	Mean weight[a] (g)	Total weight[b] (g)	Percentage of diet by weight
Brown rat	123	60	7380	35
Wood mouse	270	18	4860	23
Bank vole	199	16	3184	15
House mouse	169	12	2028	10
Pygmy shrew	95	4	380	2
Rabbit	1	350	350	2
Starling size[c]	14	74	1036	
Starling	4	82	328	
Redwing	6	65	390	
Song thrush	2	76	152	
Blackbird	2	95	190	
Skylark	2	38	76	12
House sparrow size[c]	4	22	88	
House sparrow	4	27	108	
Hedge sparrow	1	21	21	
Chaffinch	1	20	20	
Robin	4	19	77	
Wren	1	10	10	
Dunlin	1	44	44	
Common snipe	1	119	119	
Frog	13	40	520	2

[a] Estimated average weight of each species.
[b] Estimated total biomass of owls' diet (min no. × mean wt).
[c] Due to limited reference material at SRC bird remains identified here were separated into two groups, those that were approximately house sparrow size and larger birds of approximately starling size. At Manchester University where reference material was available birds were identified to species.

remainder. The pygmy shrew and frogs were present in a small proportion whether the bank vole was present or not, i.e. in the range 1–3%.

3.6 Residue analysis of pellets

The vast majority of the 89 pellets analysed, 97%, did not contain residues of brodifacoum, difenacoum an flocoumafen above the limits of determination of the analysis method, 0·01–0·02 mg kg^{-1}, for the individual *cis* and *trans* isomers. Only two pellets apparently contained rodenticide residues by HPLC analysis, and these were not confirmed by HPLC–MS examination. Moreover, the profile of results from the pellet which nominally contained flocoumafen, <0·02 mg kg^{-1} *cis* isomer and 0·08 mg kg^{-1} *trans* isomer, is in contrast with data from a radio-labelled flocoumafen feeding study.[5] This confirmed that the *trans* isomer of flocoumafen was the more labile of the two isomers and therefore not likely to occur in pellets at a higher concentration than the *cis* isomer. Thus, the positive *trans* isomer result is likely to be due to interference from co-extracted material. Although no corresponding metabolism data for difenacoum are available, the profile of results from the other pellet which nominally contained difenacoum, <0·01 mg kg^{-1} *cis* isomer and 0·14 mg kg^{-1} *trans* isomer, also indicates that the *trans* isomer result was most likely due to interference from co-extracted material. One other pellet could not be analysed because of massive co-extracted interference.

4 DISCUSSION

This study, conducted during the winter of 1988–89, indicated that Barn Owls were widespread and commonly seen in the five counties of southern Eire surveyed. The study demonstrated that it was possible to locate Barn Owl roost and nest sites, and both monitor these sites and collect pellets for prey and rodenticide residue analysis without disturbing the owls. From interviews with the farmers and landowners, methods of rodenticide control and the identities of baits used were established. Also limited information was obtained on

potential hazards to non-target animals from the use of rodenticides on their farms.

Most of the farmers interviewed (73%) used anti-coagulant rodenticide baits to control rat and/or mice infestations, and the majority of these (92%) took precautions to protect domestic and wild non-target animals from exposure to these baits. They either used the bait inside buildings only and/or hid it from view. Also, most farmers disposed of dead rodent carcasses by burying or burning.

The four rodent species, brown rat, wood mouse, house mouse and bank vole, provided 83% of the diet of the Barn Owls investigated in this study, and birds contributed another 12%. There was considerable variation between the owl sites in the contribution that the prey species made to the diet. Barn Owls appear to be opportunistic feeders and this variation is likely to reflect food availability rather than food preference. At the time of the study the distribution of the bank vole was restricted to the south-west of Eire, and it was present in the diet of all the owls studied in Co. Kerry, and the majority of those in Cork. Where the bank vole was available, the owls studied here demonstrated a preference for this rodent. The absence of the bank vole as a possible prey at the sites in the south-east, i.e. in the Co. Kilkenny, Waterford and Wexford, resulted in an increase in the consumption of the other three rodents. These observations support literature reports[13] that, where available, voles are the preferred prey of the Barn Owl.

The analytical method for the determination of residues of three second-generation rodenticides, brodifacoum, difenacoum and flocoumafen in owl pellets is considered to be a sensitive and appropriate method for the non-invasive monitoring of the exposure of Barn Owls to these rodenticides in their prey. Analysis of regurgitated owl pellets, collected during Barn Owl feeding studies,[3–6] indicates that, on average, some 25% of the amount of rodenticide consumed by the owls is regurgitated in pellets during the following 24-hour period. Assuming the consumption of a live mouse (weight 20 g) containing a rodenticide concentration of 1 mg kg^{-1} (a typical value found in live trapped mice during baiting[7]), a Barn Owl pellet (typical weight of 5 g) would contain a rodenticide residue of 1 mg kg^{-1}. This is far in excess of the limit of determination of the pellet analysis method, *c.* 0·02–0·03 mg kg^{-1} for the total isomers.

Of the 89 pellets analysed in this study, almost all (97%) contained less than the limit of determination of brodifacoum, difenacoum and flocoumafen, 0·01–0·02 mg kg^{-1}, of the individual *cis* and *trans* isomers. Only two pellets possibly contained apparent residues of the rodenticides, and there is strong evidence that co-extracted interfering material was responsible for these results. This indicates that, during the study period, none of the owls monitored was exposed to significant residues of brodifacoum, difenacoum and flocoumafen in their prey.

5 CONCLUSION

In the past it has only been possible to make an approximate assessment of the risk of secondary toxicity of second-generation rodenticides to the Barn Owl. This has been carried out by determining the total body burden of rodenticides in live or trapped rodents in baited areas and combining this data with data on toxicity and feeding habits. Approaches used to obtain data on feeding include faunal analysis of pellets,[13] the use of chemical bone markers in baits[14] and the use of radio telemetry techniques to study foraging behaviour.[13]

The field studies reported here, together with previous laboratory studies,[3–6] confirm that chemical analysis for second-generation rodenticide residues in owl pellets is both a sensitive and feasible approach to non-invasive monitoring of exposure of Barn Owls to residues in their prey. Now that the principles of the method have been successfully established, it should be possible to conduct monitoring studies of Barn Owls in other areas of regular rodenticide use to obtain an accurate assessment of exposure.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contribution of the Irish Wildlife Rangers and local amateur ornithologists in the location of Barn Owl roost and nest sites, Patricia Yalden and Manchester University for the dissection of pellets and identification of prey remains, and the assistance of colleagues, in particular Alan J. Dutton and Neal Pearson, at Shell Research Ltd, Sittingbourne Research Centre, and Sorex Ltd.

REFERENCES

1. Johnson, R. A. & Scott, R. M., *Proc. 7th Brit. Pest Control Conf.*, Guernsey, 29 May–1 June 1986.
2. Mikkola, H., *Owls of Europe*. Pitman Press, Bath, 1983.
3. Newton, I., Wyllie, I., Gray, A. & Eadsforth, C. V., *Pestic. Sci.*, **41** (1994) 187–93.
4. Gray, A., Eadsforth, C. V., Dutton, A. J. & Vaughan, J. A., *Pestic. Sci.*, **42** (1994) 179–84.
5. Eadsforth, C. V., Dutton, A. J., Harrison, E. G. & Vaughan, J. A., *Pestic. Sci.*, **32** (1991) 105–19.
6. Gray, A., Eadsforth, C. V., Dutton, A. J. & Vaughan, J. A., *Pestic. Sci.*, **41** (1994) 339–43.
7. Harrison, E. G., Porter, A. J. & Forbes, S., *Brighton Crop Prot. Conf. Monograph No. 40*, 1988, pp. 89–96.
8. Bunn, D. S., Warburton, A. B. & Wilson, R. D. S., *The Barn Owl*. Publ. T. and A. D. Poyser, London, 1982.

9. Glue, D. D., *Food of the Barn Owl in Britain and Ireland.* Bird Study 21, 1975, 200–10.
10. Fairley, J. S. & Smal, C. M., *Proc. of the Royal Irish Academy Section B—Biological Geological and Chemical Science*, Vol. 88, No. 8, 1988, pp. 119–33.
11. Yalden, D. W. *The Identification of the Remains in Owl Pellets.* The Mammal Society, Reading, 1977.
12. Lawrence, M. J. & Brown, R. W., *Mammals of Britain: Their Tracks, Trail Signs.* Blandford Press, London, 1967.
13. Hegdal, P. L. & Blaskiewicz, R. W., *Environ. Toxicol. Chem.*, **3** (1984) 167–79.
14. Crier, J. K., *J. Wildlife Man.*, **34** (1970) 829–34.